A study of Dry-Contacr Ultrasonic Transmission for Nondestructive Evaluation of Defects in IC Packages(電子パッケージ内部欠陥の非破壊評価のためのドライコンタクト超音波伝達に関する研究)

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論文内容要旨

Chapter 1　Introduction

The purpose of this work is to develop a new technique for effectively transmitting high frequency ultrasound into a sample under a dry-contact condition and to realize nondestructive evaluation (NDE) of defects in IC packages by the proposed technique. The importance of high-resolution inspection in IC packages has been recognized. In many nondestructive evaluation techniques, only the technique using the high frequency ultrasound is capable of evaluating the inner defects of integrated circuit (IC) packages such as crack, delamination and disbonding, but it has suffered from the immersion of the packages in the coupling liquid. Although several attempts for transmitting the ultrasound without using the coupling liquid have been made, these techniques are inadequate for package inspection in point of the available frequency range or the sensitivity. Therefore, a new technique for utilizing the high frequency ultrasound under a dry-contact condition is indispensable. A new technique proposed in this thesis overcome the inherent problems of the usual ultrasonic techniques, and realized the effective transmission of high frequency ultrasound into the packages under the dry-contact conditions. Also, high-resolution acoustic imaging of the defects in IC packages was made possible without getting the package wet.

Chapter 2　Proposal of a Dry-Contact Technique for Transmitting High Frequency Ultrasound

Firstly, a new technique for transmitting the high frequency ultrasound into a sample without immersing the sample into the coupling liquid was proposed. The proposed technique performs the transduction of ultrasound via a thin solid layer inserted between the coupling liquid and the sample as shown in Fig.2.5. In the proposed ultrasonic transmission system, the solid layer can also be worked as the acoustic matching layer between the coupling liquid and the sample provided that the layer takes the value of the acoustic impedance between the coupling liquid and the sample. Therefore, if the low ultrasonic attenuation in the layer and the perfect acoustic coupling between the layer and the sample surface can be realized, more effective utilization of high frequency ultrasound than the liquid immersion case is realized via the layer, in addition to the dry-contact ultrasonic transmission. The values of the acoustic impedance of various solid layers were measured, and the ultrasound generated with the 50 MHz broadband transducer was transmitted into an acrylic resin with 2 mm thick by the proposed technique using those solid layers. The used layers were made of polyvinylidene chloride (PVDC), polyvinyl chloride (PVC), polyethylene (PE) and a soft rubber, and the PVDC and PVC layers were 9 μm thick, and the PE and soft rubber layers were 13 and 200 μm thick, respectively. The used coupling liquid was water, and the measured values of the acoustic impedance of used layers ranged between those of the resin and water. Also, for improving the acoustic coupling at the layer/sample interface, the atmospheric pressure of about 0.1 MPa was applied to the interface by evacuating the air between the layer and the sample. It was experimentally confirmed that the ultrasound exited with the 50 MHz transducer was transmitted into the resin via all of those layers.

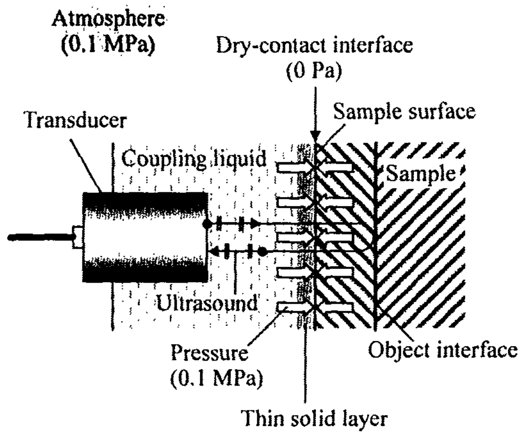

Fig. 2.5 Schematic illustration of the dry-contact ultrasonic technique.

Chapter 3 Requirements for a Thin Solid Layer to Realize High-Resolution Acoustic Imaging under a Dry-Contact Condition

To investigate the requirements for a thin solid layer to realize high-resolution acoustic imaging under a dry-contact condition, the ultrasonic attenuation coefficient of the PVDC, PVC, PE and soft rubber layers was measured. The ultrasonic transmission into a plate of acrylic resin was performed by the 30 and 100 MHz broadband transducers under the proposed dry-contact condition through those layers and the usual water immersion condition. The signal-to-noise ratio (SNR) and the lateral resolution were determined from the back-wall echoes of the resin obtained by the 30, 50 and 100 MHz transducers under the dry-contact and the water immersion. The coupling loss at the layer/resin interfaces was determined by comparing the amplitude spectra of the back-wall echoes with the theoretical model. The coupling loss at the layer/resin interface, which was described as the coupling coefficient in this thesis, tended to increase with increasing in the nominal frequencies of the used transducers due to the detachment of the layer from the resin surface during the ultrasonic transmission. SNR is governed by the coupling coefficient, and the lateral resolution is affected by the ultrasonic attenuation in the layer. For realizing high-resolution acoustic imaging via a solid layer, the layer is required to attach on the sample surface throughout the ultrasonic transmission, and must realize the low ultrasonic attenuation. The low ultrasonic attenuation in the layer can be realized by utilizing the layer with the low ultrasonic attenuation coefficient or the very thin layer. In the examined high frequency range, PVDC and PVC layers realized the perfect acoustic coupling to the resin under the proposed dry-contact condition. Therefore, very thin layers made of PVDC and PVC realized high SNR and high lateral resolution, which equal those of the usual water immersion case, for all used transducers.

Chapter 4 Development of a Dry-Contact Scanning Acoustic Microscope and Its Application to IC Package Inspection

Based on the principle of the proposed dry-contact technique, a dry-contact scanning acoustic microscope (D-SAM) was developed for realizing the acoustic imaging of an object interface in IC package without getting the package wet. Acoustic imaging of actual IC packages with various surface roughness was carried out by the developed D-SAM and the usual ultrasonic C-scan imaging system. The 50 MHz focused transducer was used for every imaging. The jointing shape of the ball-grid-array solder joints and the delamination between the chip and chip pad in a package were clearly imaged by the developed D-SAM, and it was also confirmed that D-SAM is capable of acquiring high SNR acoustic images of actual packages as the usual C-scan system. Especially, the delamination between the epoxy resin and the chip pad in a package was obscure in the usual C-scan image due to the water invasion into the package [Fig. 4.7(b)], but it was clear in the present D-SAM image shown in Fig. 4.7(a).

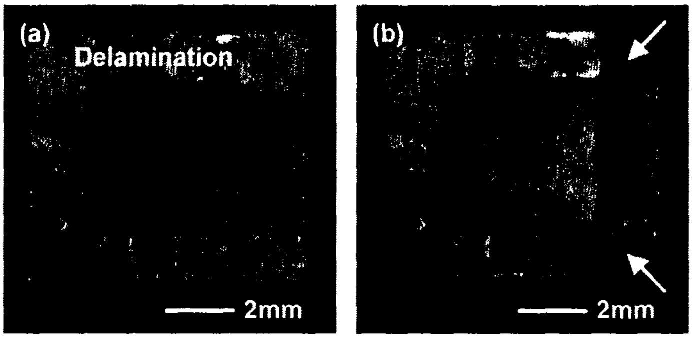

Fig. 4.7 Acoustic images of the delamination between the epoxy resin and the chip pad in FBGA package obtained by the 50 MHz transducer. (a) Present D-SAM using the PVC layer. (b) Usual C-scan system. The delamination parts faded by the water invasion are indicated by the arrows.

Chapter 5 Design and Performance of Frequency Filters Using a Thin Solid Layer for High-Resolution Acoustic Imaging

For producing the higher quality acoustic images over the usual C-scan images, a theoretical model to calculate the amplitude ratio of the dry-contact case to the water immersion case was elaborated. The calculated amplitude ratio is a function of frequency and the layer thickness, and the amplitude ratio, which was calculated on the ultrasonic transmission system from water to silicon, takes positive values at the combinations of a frequency and a layer thickness in the cases of inserting the PVDC [Fig. 5.3] and PVC layers. By selecting the layer thickness based on the calculated amplitude ratio, two frequency filters using a thin solid layer can be designed. One is the filter of the signal amplification for the SNR enhancement, and another is that of the signal modulation toward the higher frequency components for improving the spatial resolution. To confirm the validity of the theoretical model and the realization of those filters, the ultrasonic transmission into the sample in which a silicon chip was embedded in the epoxy resin was carried out through the designed layers. The 30, 50 and 100 MHz broadband transducers were used in the transmission. The PVDC and PVC layers designed based on the theoretical model were 9 μm thick where the ultrasound exited with the 100 MHz transducer is much amplified. The calculated amplitude ratio was in good agreement with the experimental one as shown in Fig. 5.7(a). Those layers well worked as the frequency filters, hence the signal amplification for all used transducers and the signal modulation toward the higher frequency components for the 30 and 50 MHz transducers were realized. Furthermore, the solder joints of a wafer level package having bare silicon chip were visualized by D-SAM with those frequency filters and the usual C-scan system. In the case of the 50 MHz transducer, usual C-scan system could hardly detect the defective joint, but

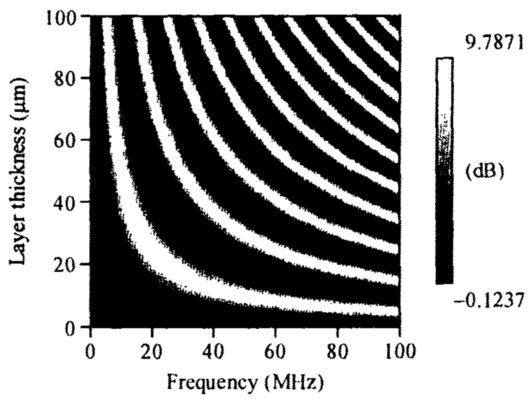

Fig. 5.3 Amplitude ratio calculated on the ultrasonic transmission system from water to silicon through the PVDC layer.

the present D-SAM clearly detected it by improvement of the spatial resolution. Also, the quality of the acoustic image obtained by the 100 MHz transducer was remarkably improved by the SNR enhancement of the present D-SAM. The frequency filters using a thin solid layer is useful for quality improvement of the acoustic images.

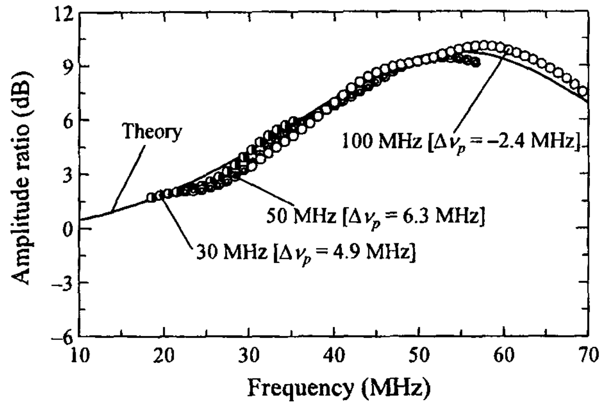

Fig. 5.7(a) Comparison between the theoretical amplitude ratio and the experimental one for the 30, 50 and 100 MHz transducers (PVDC layer). The values of the signal modulation are shown as Δv_p.

Chapter 6 Effective Transmission of High Frequency Ultrasound under a Dry-Contact Condition Using Rubber

For realizing the cyclic acoustic imaging under a dry-contact condition, the effective transmission of high frequency ultrasound through a soft rubber was investigated. Firstly, the cycle tests were performed to four kinds of soft rubbers with 0.2 mm thick, and Young's modulus and the energy loss of the rubbers were determined. The acoustic impedance and the ultrasonic attenuation coefficient of those rubbers were also measured. The ultrasonic attenuation in the rubber was mainly due to the heat generation in the rubber accompanied with the elastic deformation, and the rubber with low energy loss gave the low ultrasonic attenuation in the rubber. The ultrasonic transmission into the acrylic resins with different surface roughness was carried out by the 50 MHz broadband transducer, and the coupling loss at the rubber/resin interface was determined. The coupling loss at the rubber/resin interface was increased with increasing the surface roughness of the resins, and it can be correlated with Young's modulus of the rubbers. The rubber with the lowest value of Young's modulus realized the best acoustic coupling to the resins with roughened surface in the examined rubbers. To perform the high quality acoustic imaging through a rubber, the rubber must take low energy loss and low Young's modulus. The cyclic acoustic imaging of the delamination in a package was carried out through the rubber selected on the energy loss and Young's modulus, and the delamination was repeatedly visualized. The quality of the acoustic images was never degraded during the cyclic imaging.

Chapter 7 Conclusions

This research gives the first success in the effective transduction of high frequency ultrasound under a dry-contact condition. A new dry-contact scanning acoustic microscope developed on the proposed technique is the only system that can nondestructively evaluate the defects in IC packages such as crack, delamination and disbonding without getting the packages wet. The proposed technique must be profitable and valuable in not only the present electronics industry but also the future one, and it will certainly become the powerful tool for ensuring the reliability and the quality of the electronic components and devices.

論文審査結果の要旨

電子パッケージの検査に超音波が広く用いられている。高周波数超音波を用いた映像法はパッケージ内部の欠陥を高分解能に可視化できることから、欠陥の定量評価に好適であるが、従来の超音波法では検査時にパッケージの水没が不可欠であるため、液体音響媒体へ没入せずに高周波数超音波を伝達し得る手法の開発が切に待たれていた。

著者は、検査対象の非水没下における高周波数超音波の伝達手法の開発に成功した。本論文は同伝達手法とこれに基づき開発した映像検査システムによる非水没下での電子パッケージ内部欠陥の定量的評価についてまとめたもので、全編７章よりなる。

第１章は序論である。

第２章では、液体音響媒体と検査対象との間に固体薄層を介し、減圧により薄層と検査対象との接触界面に約 0.1MPa の大気圧を作用させた状態で高周波数超音波を伝達する手法を提案するとともに、同伝達法による試験体への高周波数超音波伝達に成功している。これはドライコンタクト超音波伝達の基礎を与える有益な成果である。

第３章では、薄層内での低超音波減衰を実現し、超音波伝達時の弾性変形によっても検査対象表面から離れない薄層を用いることで高周波数超音波が高効率に伝達できることを見い出すとともに、このような特性を有する数種類の高分子材料を特定している。本薄層要件の特定は有用な成果である。

第４章では、ドライコンタクト法を利用した超音波映像装置を開発し、実際の電子パッケージ内部欠陥の非水没下における高分解能可視化に成功している。これは他に先駆けた成果である。

第５章では、挿入する固体薄層を液体音響媒体と検査対象との間の音響整合層として機能させるために理論モデルを提案し、挿入することで水没時を上回る高強度で高周波数の超音波が受信できる薄層の設計に成功している。さらにこれを用い、実装後パッケージのはんだ接合部検査を実施し、非水没下に加えて水没時を上回る高画質な音響イメージの収録に成功している。これは他に先駆けた成果である。

第６章では、低い縦弾性係数を有し低エネルギー損失のラバーによりラバー内での超音波減衰損失、ラバーと検査対象との接触界面での伝達損失が低減できることを示し、繰返し利用可能なラバーを用いたドライコンタクト下での高効率超音波伝達を実現している。これは実用にあたり有益な成果である。

第７章は結論である。

以上要するに本論文は、検査対象の非水没下における高周波数超音波の伝達手法を新たに開発して、電子パッケージの非水没下における内部欠陥の高分解能可視化を可能にしたもので、機械知能工学の発展に寄与するところが少なくない。

よって、本論文は博士（工学）の学位論文として合格と認める。